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14. ABSTRACT
THE OBJECTIVE OF THIS ADDITIONAL WORK EFFORT IS TO PROVIDE THE CONCEPTUAL FOUNDATIONS FOR DESIGNING MINIATURE ANTENNAS HAVING GREATER MODE DIVERSITY FNA BANDWIDTH BY THE INCORPORATION OF MAGNETIC MATERIALS. THE PI AND A GRAUDATE STUDENT WILL EXPLORE THE INCORPORATION OF CERTAIN MAGNETIC MATERIALS (PARTICULARYLY METAFERRITES) IN THE ANTENNA SUBSTRATE. THEY WILL ALSO EXPLORE THE POSSIBLE MONRECIPROCAL BEHAVIOR THE SUCH MATERIALS MIGHT EXHIBIT. THE AF ANTICIPATES FIELDING SMALLER AND MORE AGILE ANTENNAS ON ITS EXPANDING FLEET OF UAVs AND THE RESEARCH PURSUED HERE WILL SPEAK TO THAT GOAL.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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AFOSR MURI Transition Projects

Conformal Antenna and Array Design Using Novel Electronic Materials: FA 9550-04-1-0359

This MURI was about the invention/discovery, analysis, demonstration and realization of novel propagation modes that led to extremely slow waves (as photonic crystal modes) in textured or layered dielectric media (metamaterials). Of importance is that these modes are non-reflecting at the air-dielectric interfaces. As a result, the efficiency of the receiving or transmitting antennas based on these modes is extremely high, even though the antenna structure is very small.

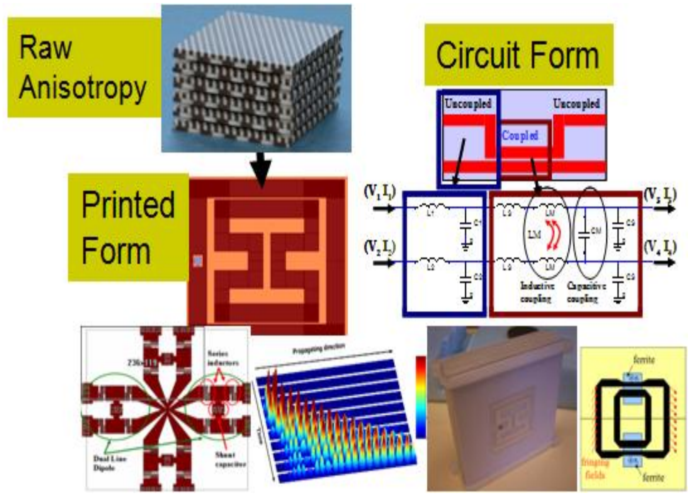

Fig. 1. Volumetric anisotropic media with corresponding equivalent printed circuits having the same properties (using low cost uniform substrates). This patented technology was developed under the AFSOR MURI, and is the most promising for transformational impact on all aspects of RF/EO applications

A key discovery during the course of the MURI was the realization of such anisotropic media in a planar configuration using simple printed microstrip lines (coupled lines, possibly loaded with lumped elements such as capacitors and inductors, see Fig. 1). This discovery led to many new and easy to manufacture miniature antennas. Because of their very low cost, order of magnitude in size reduction, and conformal nature, these antennas are finding transition in many ubiquitous applications.

It is well known that the inclusion of low loss ferrites within the substrate of the printed coupled lines will significantly enhance bandwidth and radiation. A concept that includes ferrite inserts printed structures is depicted in Fig. 2. Currently, we are examining modes that can be realized using these structures to motivated

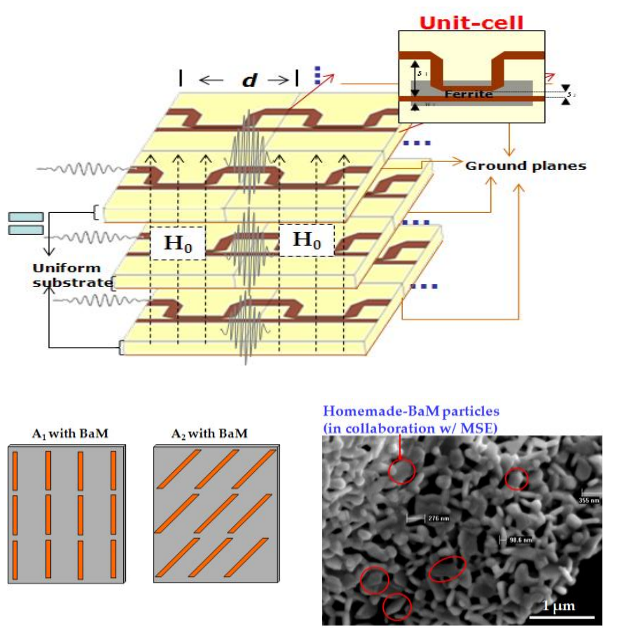

Fig. 2. **Top:** Artificially realized nisotropic media exhibiting novel phenomena using low cost layered coupled lines, with possible ferrite inserts for mode diversity and bandwidth increase. **Bottom:** Printing on low loss hexaferrite (BaM) fabricated at Ohio State using uniform small platelets, formed as low as 700°C, by Pechini method. Due to demag., it is necessary to use ferrites with low $4\pi M_s$ (500-600G) to assure saturation. These ferrite layers can be used with the coupled transmission lines to realize a diversity of modes, and more importantly bandwidth.

future research in developing low loss magnetic materials. An example of low loss ferrites with aligned platelets via the Pechini method is also depicted in Fig 2.

Two example transition projects were recently awarded by AFRL to exploit the smaller antennas and arrays that can be realized using the low cost metamaterials developed under the referenced AFOSR. They are

AFRL Contract No. FA8650-09-C-1656
Award to *Lockheed Martin Corp.* (Skunk Works, Palmdale, CA, charles.chase@lmco.com) in Oct 2009 with subcontract to Ohio State. Phase I: 9 months (Phase II is subject to progress and review in May 2010)
Title: *Metamaterials for RF Applications*
This project exploits the much smaller developed metamaterial antenna elements (at least 5 times smaller) to realize wideband metamaterial arrays. As is well known, array elements must be no more than $\lambda/2$ apart (center to center) to suppress potential grating lobes. This limits the possibilities of designing wideband arrays. However, if the antenna element is $\lambda/4$ in length at f_L and still resonate, the array can potentially achieve a 2:1 bandwidth (one octave) as the element to element separation will be $\lambda/2$ when the frequency reaches $f_U=2f_L$. Correspondingly, as the new MURI antenna elements are $\lambda/10$ in size, the potential array bandwidth can be a remarkable 5:1. Coupling between multiple elements allows for even lower resonances when the individual elements are only $\lambda/20$ in size, implying a 10:1 array bandwidth.

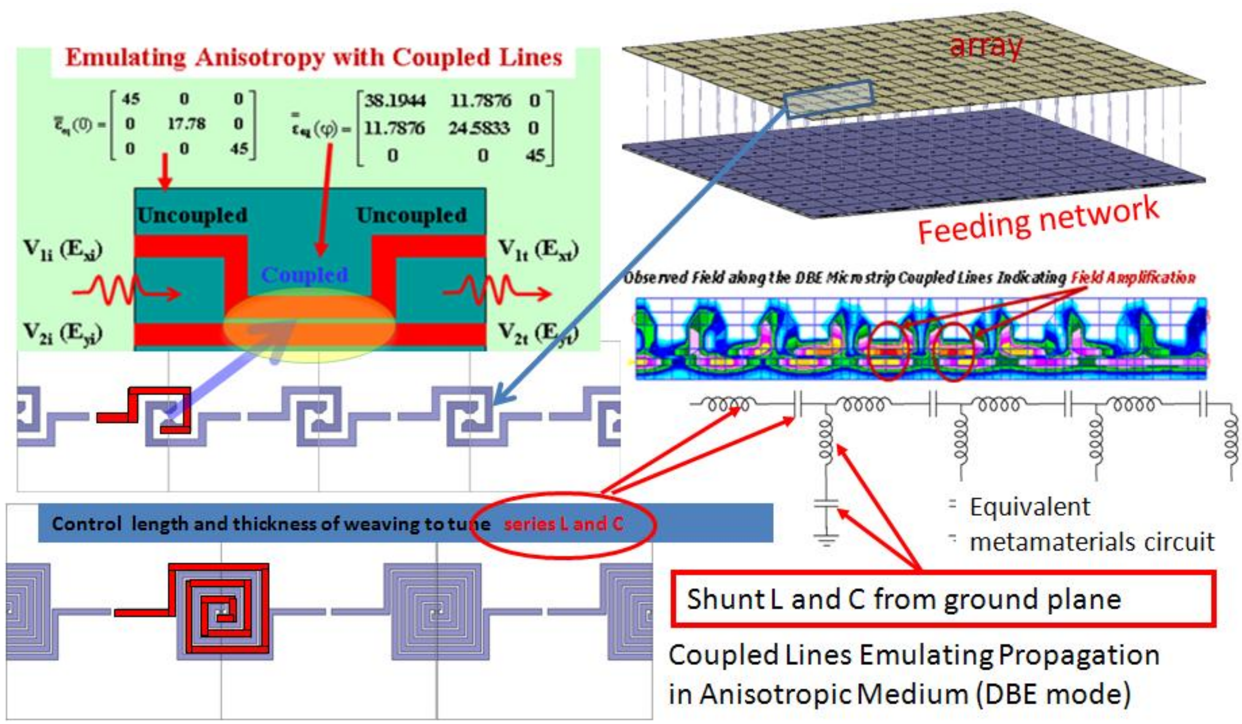

Figure 3. Miniature ultrawideband aperture formed by interconnected metamaterial antenna elements. The latter were developed under the MURI program and were interconnected to form small wideband metamaterial arrays. Remarkably, as much as 10:1 and 20:1 bandwidths have been theoretically demonstrated for conformal apertures by exploiting the current sheet realization introduced by the late Ben Munk at the Ohio State Univ. (building on previous concepts introduced by Wheeler)

Under this AFRL transition project, Ohio State is helping LMC develop a reduced size FOPEN (foliage penetration) array. Current FOPEN is large and heavy, and must be installed as an appendage below the airborne vehicle. Under this effort, the array will be reduced in size by at least a factor of 2 per linear dimension. More importantly, it will be designed for conformal installations using the concepts outlined in Fig. 3.

AFRL Contract No. FA8650-09-C-1658
Award to *Boeing Corp.* (Seattle, WA, grant.e.davis@boeing.com) in Oct 2009 with subcontract to Ohio State. Phase I: 9 months (Phase II is subject to progress and review in May 2010)
Title: *Metamaterials Broadband Direction Finding Antenna Development*

The aim of this project is to replace current blade antenna that are highly protruding and impede airframe take-off (retracted during take-off to avoid being damaged). Currently, 3 blade antennas are used to cover the band of 30-500MHz for direction finding purposes. The newly proposed antenna is a miniature spiral incorporating volumetric coiling for size reduction that nearly reaches the optimal limits. To retain its performance in conformal installations, a metamaterial ground plane, constructed from textured, substrates will be adapted as depicted in Fig. 4.

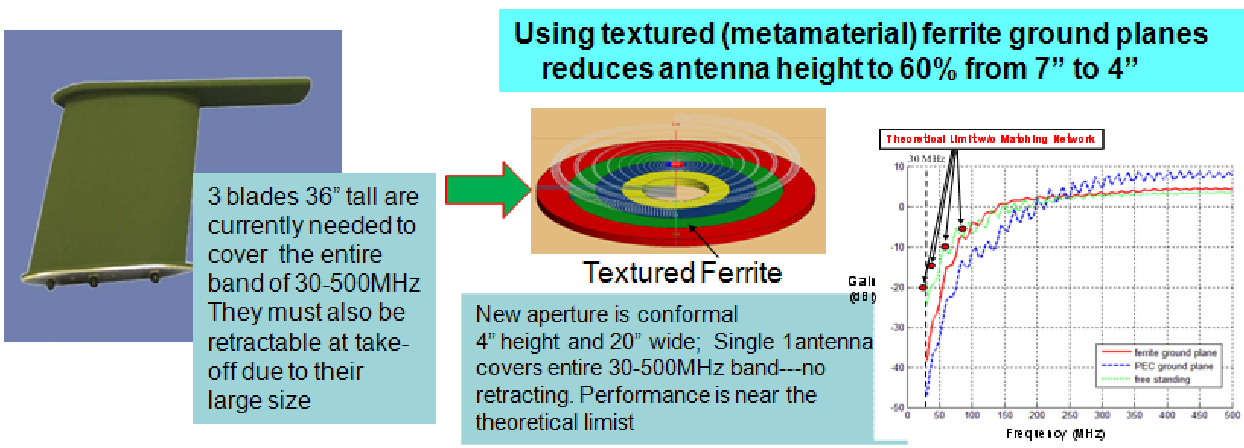

Figure 4. Miniature conformal spirals on textured/metamaterial ferrite substrates (middle) to replace traditional blade antennas that protrude nearly 1meter above the airframes surface, and require retraction for take-off. New antenna will be only 3"-4" in height, and will replace 3 separate 1meter tall blades needed to cover the entire band of 30-500MHz.